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The E687 Collaboration

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A measurement of the lifetime of the charmed strange baryon Ξ_c^0 is presented. The data were accumulated by the Fermilab high energy photoproduction experiment E687. The measurement has been made using 42 ± 10 $\Xi_c^0 \to \Xi^- \pi^+$ decays. The lifetime of the Ξ_c^0 is measured to be $0.101^{+0.025}_{-0.017} \pm 0.005$ ps and its mass is measured to be $2462.1 \pm 3.1 \pm 1.4$ MeV/c^2.

A lifetime measurement of the Ξ_c^0 (csd) has thus far been very elusive, primarily due to the low production rate. Only one other experiment has made a measurement of the lifetime of Ξ_c^0 [1], using very low statistics. The ACCMOR collaboration observed four decays of $\Xi_c^0 \to pK^-\overline{K}^*(892)^0$ (references to a specific charge state should be taken to include the charge conjugate state) and measured a Ξ_c^0 lifetime of $0.082^{+0.059}_{-0.030}$ ps. This letter reports a new lifetime measurement of the Ξ_c^0 based on a sample of 42 ± 10 events decaying into $\Xi^- \pi^+$.

The data were collected in the Fermilab photoproduction experiment E687 during the 1990-91 run period. Approximately 500 million hadronic triggers were recorded on tape.

The E687 detector, which is described in detail elsewhere [2], is a large aperture spectrometer with good detection capabilities for charged hadrons and photons. The experiment uses a photon beam of mean energy $\sim$ 220 GeV impinging on a beryllium target. A microvertex detector consisting of 12 planes of silicon microstrips arranged in three views provides high resolution tracking. Deflection of charged particles by two analyzing magnets of opposite polarity is measured by five stations of multiwire proportional chambers (PWCs). Three multicell Čerenkov counters operating in threshold mode are used for particle identification.

The Ξ^-'s are fully reconstructed through the decay channel $\Xi^- \rightarrow \Lambda^0\pi^-$, with the Λ^0 being reconstructed through the $p\pi^-$ decay channel. Decays which occur downstream of the microstrip detectors are reconstructed by intersecting the daughter π^- track and the Λ^0 and by requiring that the direction of the resultant momentum vector agree to within two milliradians with an unmatched microstrip track (the Ξ^- candidate track). In order to remove contamination from $\Omega^- \rightarrow \Lambda^0K^-$ decays the daughter π^- from the Ξ^- is required to be identified by the Čerenkov system as being neither a definite kaon nor ambiguous between a kaon and a proton. Fig. 1 shows the $\Lambda^0\pi^-$ invariant mass plot for the decays which occur downstream of the silicon microstrip detectors. Only the downstream decays are used because of the important advantage of having an observed hyperon track in the microstrip detector. This does not significantly reduce the efficiency for reconstructing charmed baryon states since 85% of our Ξ^- signal comes from the downstream decays.

The $\Xi^-\pi^+$ combinations are obtained using a candidate–driven vertex finder which is described in detail in Reference [2]. We first select only those Ξ^-'s which have a mass within ± 10 MeV/c^2 of the Particle Data Group value [3] and π^+'s which are identified by the Čerenkov detectors as being consistent with pions. The secondary vertex formed from the Ξ^- and π^+ silicon tracks is required to have a confidence level greater than 20%. A primary vertex is formed from the $\Xi^-\pi^+$ *seed track* (the sum of the Ξ^- and π^+ momentum vectors) and other unused silicon tracks in the event which are consistent with intersecting the seed track. Finally, the distance, L, between the primary and secondary vertex is calculated and divided by its error, σ_L, to obtain the quantity L/σ_L.

We also use a secondary vertex *isolation* cut which effectively reduces the background from higher multiplicity vertices. Silicon tracks which are not used in the candidate primary or secondary vertices are forced into the secondary vertex. A confidence level for this new higher multiplicity vertex is then computed. We require that this confidence level be less than 1%.

Fig. 2 shows the $\Xi^-\pi^+$ invariant mass distribution for a significance of separation cut of $L/\sigma_L > 0.5$. The distribution is fitted with a Gaussian for the signal and a second order polynomial for the background. The width of the Gaussian is fixed at 10 MeV/c^2, the value obtained from Monte Carlo studies for the mass resolution of the state. We measure the Ξ_c^0 mass to be 2462.1 $\pm$ 3.1 (statistical) $\pm$1.4 MeV/c^2 (systematic). The systematic error was obtained by comparing our observed masses for the decays $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^-\pi^+\pi^+$, $D^+ \to K^-\pi^+\pi^+$ and $\Lambda_c^+ \to pK^-\pi^+$ with their accepted values [2]. The yield of the fit is 42 ± 10 events.

The Ξ_c^0 lifetime has been measured using a *binned maximum likelihood* fitting procedure which is described in detail in Reference [4]. The fit is made to the *reduced proper time* distribution. We define the reduced proper time variable, t', as $t' = (L - N\sigma_L)/\beta\gamma c$, where N is the significance of separation cut ($L/\sigma_L > N$) and $\beta\gamma$ is the Lorentz boost factor to the Ξ_c^0 center of mass frame. As Monte Carlo studies have shown that σ_L is independent of L, the t' distribution of decaying Ξ_c^0's takes the form $e^{-t'/\tau}$, where τ is the Ξ_c^0 lifetime.

A fit is made to the t' distribution of events within a region $\pm 2\sigma$ around the fitted Ξ_c^0 mass ($\pm$20 MeV/c^2). The predicted number of events in a reduced proper time bin centered at t' is given by

$$n_i = S\frac{f(t_i')e^{-t_i'/\tau}}{\Sigma f(t_i')e^{-t_i'/\tau}} + B\frac{b_i}{\Sigma b_i},$$

where $S = N - B$, N is the total number of events in the signal mass region, $f(t')$ is a correction function and b_i describes the background reduced proper time evolution. High and low mass sidebands equal in width to the signal region and separated from the signal by 5σ are used to determine b_i. The fit parameters are τ and B. Twenty five reduced proper time bins were used to span the region from 0 to 0.5 ps.

The reduced proper time evolution for the signal is modified by a correction function, $f(t')$, which corrects for the effects of acceptance, analysis cuts and hadronic absorption of the Ξ_c^0 daughters. Fig. 3 shows the $f(t')$ distribution for the Ξ_c^0 sample shown in Fig. 2. The increase in $f(t')$ as t' increases is due to the increase in efficiency of the secondary vertex isolation cut for larger separations of the primary and secondary vertices.

Studies in which a thousand independent Monte Carlo experiments were generated, with great care taken in the modeling of the background lifetime evolution, confirmed that the size of the statistical errors from the fit are accurate. Fig. 4 shows the Ξ_c^0 lifetime for L/σ_L cuts ranging from 0.5 to 1. No significant variation in the fitted lifetime is observed. We choose to quote the final lifetime result at a value of $L/\sigma_L > 0.5$, where the statistical errors are smallest and the signal to noise ratio is good. The fitted lifetime is $\tau(\Xi_c^0) = 0.101^{+0.025}_{-0.017}$ ps. In Fig. 5 the background subtracted, $f(t')$ corrected reduced proper time distribution is plotted for events in the signal region. The overlayed curve is a pure exponential using the lifetime found from the fit.

A small systematic error of 0.004 ps is ascribed to uncertainties in the background lifetime evolution. This was estimated by using different background sidebands as well as different fractions of the high and low mass sidebands in the fit and looking at the changes in the lifetime. Other systematic studies such as fitting to the proper time distribution rather than the reduced proper time distribution and varying the number of bins used in the fit showed no significant variance in the fitted lifetime result. Finally, an additional systematic uncertainty of 0.003 ps is attributed to uncertainties in the secondary absorption correction. This uncertainty arises from not knowing how much elastic scattering of the secondaries causes significant mismeasurement of the parent Ξ_c^0.

The final value for the Ξ_c^0 lifetime is $0.101^{+0.025}_{-0.017}$ (statistical) ± 0.005 (systematic) ps. This measurement is in agreement with ACCMOR's low statistics Ξ_c^0 lifetime measurement of $0.082^{+0.059}_{-0.030}$ ps, and is consistent with the theoretical models of Guberina *et al.* [5] and of Voloshin and Shifman [6] for the charmed baryon lifetime hierarchy. These models predict $\tau(\Xi_c^0) < \tau(\Lambda_c^+)$, where the inequality represents a factor of 1.5–1.7. Using our result and the result from the compilation of the Particle Data Group [3] for the Λ_c^+ lifetime, we find the ratio $\tau(\Lambda_c^+)/\tau(\Xi_c^0)$ to be $1.89^{+0.35}_{-0.48}$.

In summary, we report a lifetime measurement of the charmed strange baryon Ξ_c^0 decaying in the mode $\Xi^-\pi^+$, using a precision microvertex detector. From a sample of 42 ± 10 events we measure a lifetime of $\tau(\Xi_c^0) = 0.101^{+0.025}_{-0.017} \pm 0.005$ ps and a mass of $2462.1 \pm 3.1 \pm 1.4$ MeV/c^2.

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Figure Captions

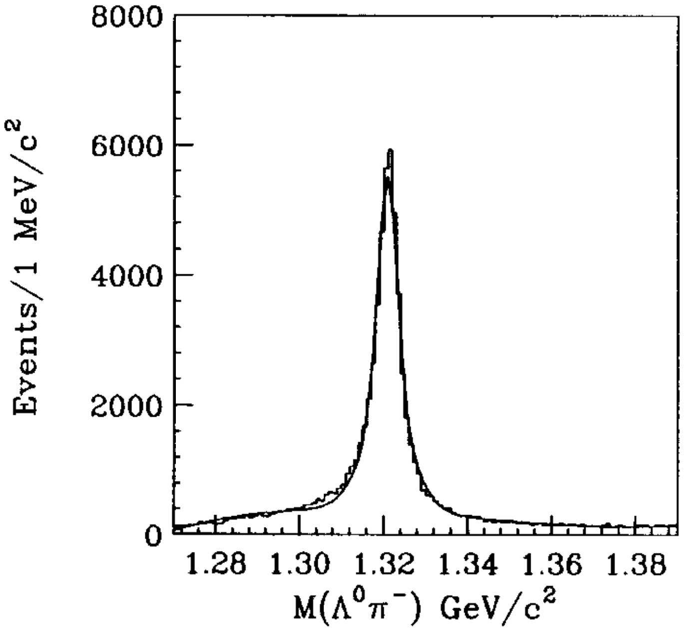
Fig. 1: $\Xi^- \to \Lambda^0\pi^-$ candidates with decay vertex between the microstrip detectors and the first PWC plane. The yield is 43110 ± 255 events.

Fig. 2: $\Xi^-\pi^+$ invariant mass distribution with cuts as described in the text. The significance of detachment cut is $L/\sigma_L > 0.5$.

Fig. 3: The Monte Carlo correction function, $f(t')$, which measures the deviation from a pure exponential decay.

Fig. 4: Fitted lifetime of the Ξ_c^0 versus the significance of detachment cut, L/σ_L.

Fig. 5: Background subtracted, Monte Carlo corrected, reduced proper time distribution for events in the region $\pm 2\sigma$ around the measured Ξ_c^0 mass. The superimposed curve is a pure exponential using the Ξ_c^0 lifetime found by the fit.



8000
6000
4000
2000
0
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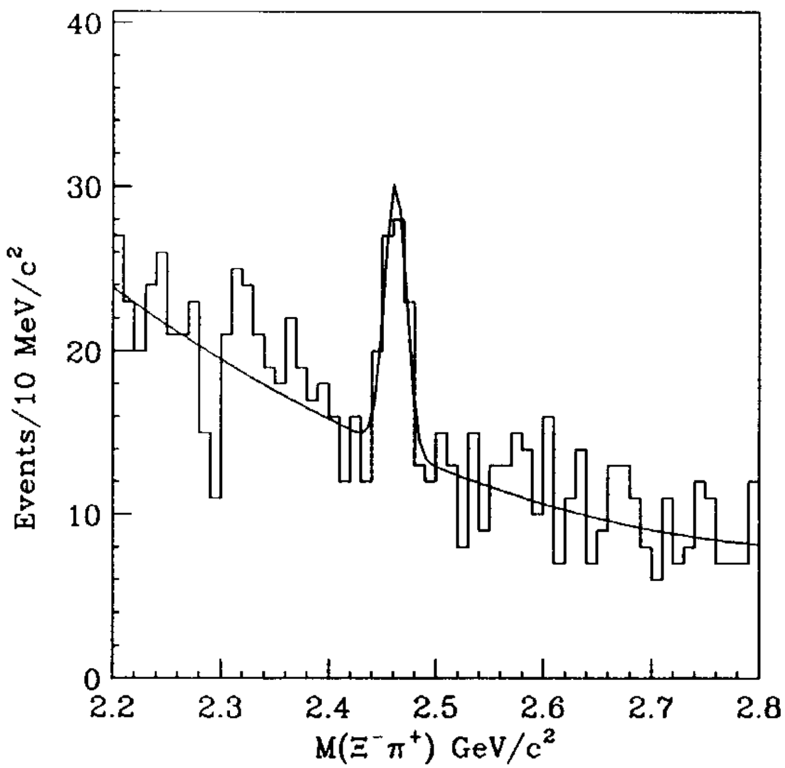
1.28 1.30 1.32 1.34 1.36 1.38
M(Λ⁰π⁻) GeV/c²



Events/10 MeV/c^2
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30
20
10
0
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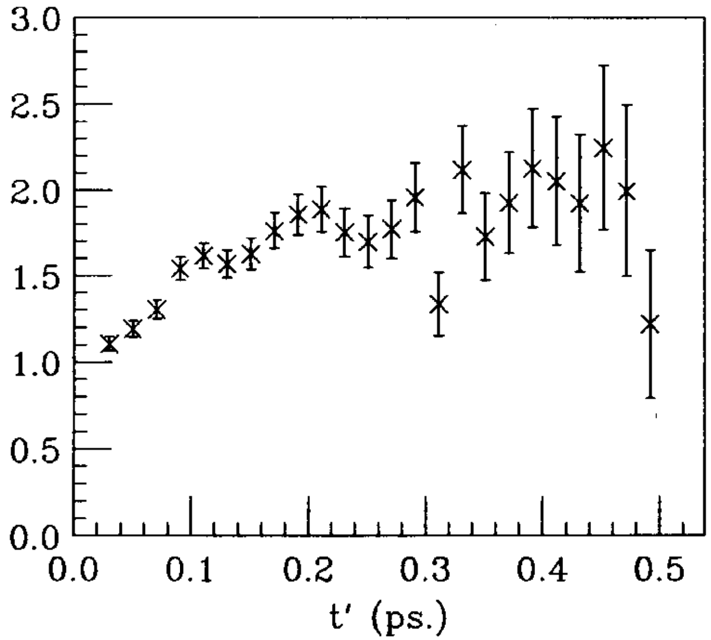
2.3
2.4
2.5
2.6
2.7
2.8
M($\Xi^-\pi^+$) GeV/c^2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2.5
2.0
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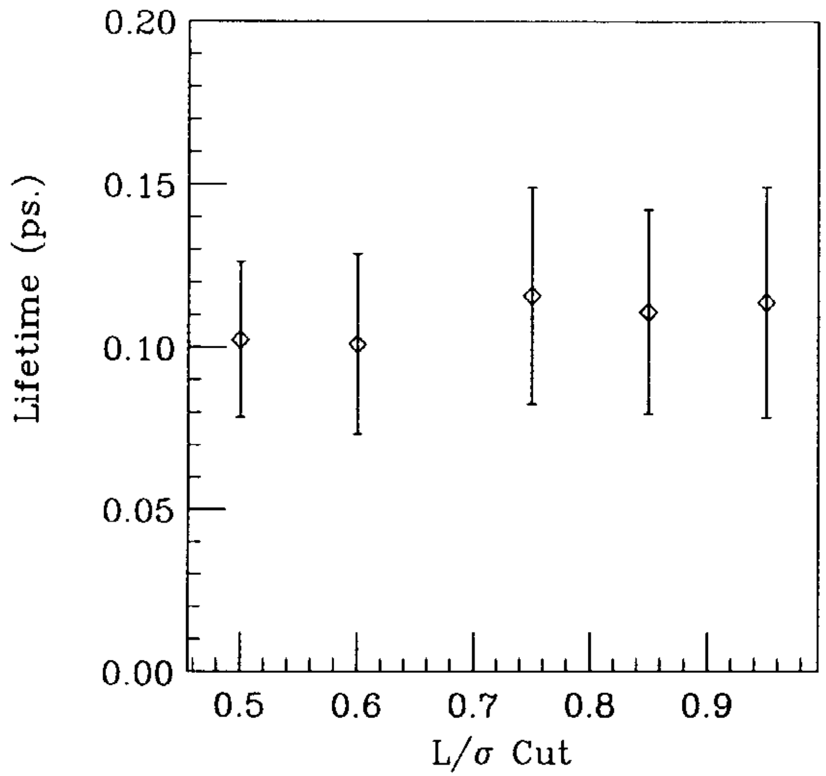
1.0
0.5
0.0
0.0
0.1
0.2
0.3
0.4
0.5
t′ (ps.)


Lifetime (ps.)
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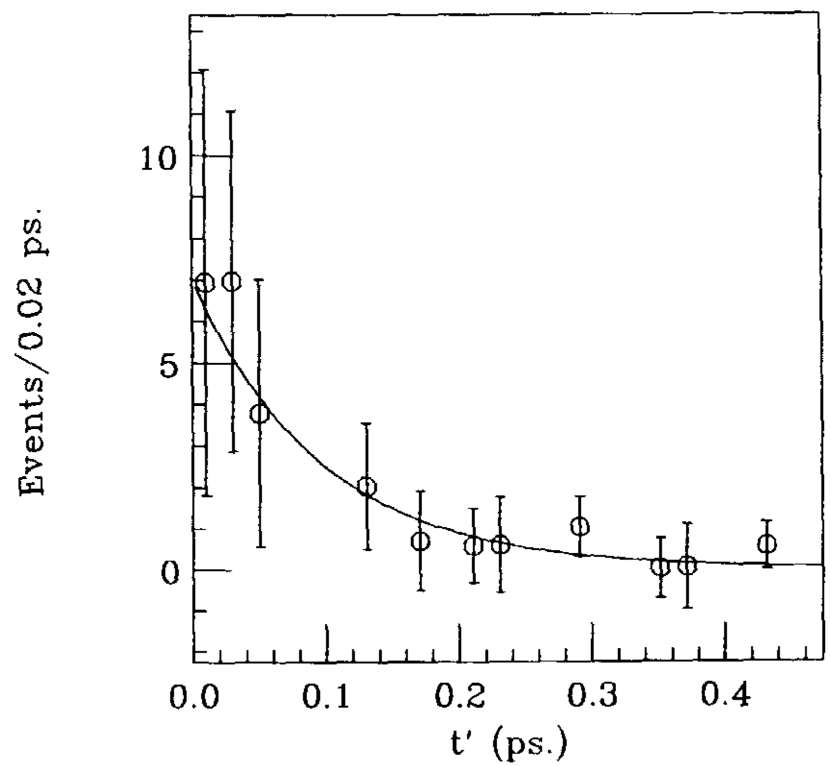
0.10
0.05
0.00
0.5
0.6
0.7
0.8
0.9
L/σ Cut


Events/0.02 ps.
10
5
0
0.0
0.1
0.2
0.3
0.4
t' (ps.)